Protection of Building Constructions with Sulfur Impregnating Solution

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Abstract

A new kind of impregnation compound has been created on the basis of long-term studies in the sphere of durability increase for porous construction materials (cement concrete, lime-sand brick, and autoclave aerocrete) by reducing water absorption through impregnation. The compound is sulfur-containing water solution, stabilized with special additives. High penetrability and molecule size of the impregnation compound (less than 0.5 nm) provide penetration of the solution into $1\text{-}10^4$ nm radius pores. The impregnation is carried out by immersing the items into the impregnation compound for 0.5-6.0 hours or by repetitive brushing. The depth of impregnation compound penetration into material structure is 15-40 mm. Treatment with impregnation solution results in hydrophobic coating formed on the surface, consisting of nanosize sulfur particles, with strong adhesion to any nonorganic surfaces. The composition that is not washed away with water, possesses bactericidal properties. Impregnated with sulfur-containing compound building materials have low water absorption, retain low vapour permeability, possess high freeze resistance and durability under atmospheric impact, which allows protecting building units and constructions for a long period of time.

Keywords

Sulfur; Nanoparticles; Impregnation; Hydrophobization; Concrete; Polysulfide

Introduction

The principal cause for the degradation of building construction is atmospheric and chemical factor. Aggressive chemical and atmospheric components, conditioning carbonization, sulfate accumulation, chloride reactions, freeze-thaw cycles, increase of the mechanical impact–all these factors lead to crack formation, reduction of water resistance, and solidity for concrete and other building materials. All the known building materials (concrete, brick, schist, gypsum, limestone, and others) that are porous and hydrophilic, get moistened when contacting with water, and easily penetrates into the porous space of the materials. Water acts as a medium for all aggressive agents and chemical reactions, as described above. Thus, it doesn't take much to appreciate the significance of dampproofing for concrete and other building materials. Even without aggressive chemical agents, water can cause serious deterioration by infiltration through concrete pores or through low-quality concrete. Penetration into the material pores, water gradually dissolves and washes out the components, composing concrete and brick. As a result, the material loses its durability and crumbles (see FIG. 1). Deterioration process is accelerated, in case the building or construction material is constantly exposed to "freeze-thaw" cycles, when water transfers into ice in the porous space, it increases in volume (approximately by 9%) and creates inner pressure, causing crack formation.

FIG. 1 EXAMPLES OF WATER DETERIORATING IMPACT ON BUILDING FACADES AND UNDERGROUND CONSTRUCTIONS

The most effective way to prevent material degradation is the use of various protective compounds. Currently, there are lots of protective coatings for building materials, however, most of them maintain their protective properties only for a limited

period of time (2-3 years). Recoating facades is needed later as a result of the previous protective layer destruction. Protection of buildings and constructions from underground water poses even more daunting problem.

The application of protective coverings under natural-anthropogenic impact increases durability of buildings and constructions by reducing volume of water penetrating into the pores. Filling construction material pores with impregnation compound allows closing out damp from the porous space, thus protecting the material from deterioration.

Building constructions and materials are exposed to water impact to a different degree. For instance, building facades are exposed to rain water. Well-known facade paints with plastic binder are used for protection, as well as organosilicon compounds which form thin 1-3 mm hydrophobic layer, preventing water from penetration into materials. Other constructions are exposed to underground water and moisture: foundation blocks, flumes, wells, walls of the basement floors, poling, arches, bridging, curbing, paving tile, elements of bridge constructions, pipe culverts, and others. Thin protective compound layer on the material surface will not do. Compositions, capable to penetrate into the depth of the material and to protect it from water at its constant presence are necessary.

In the cases indicated above, various bonding media (polymer, organosilicon, liquid glass, sulfur melts, and others) are used [1,7]. Each of the listed materials has its drawbacks. For example, organic and organosilicon compounds, in spite of their high efficiency in the beginning of exploitation, get gradually destructed and lose their protective properties. Silicate paints based on the liquid glass also have their drawbacks, being friable, possess less hydrophobicity, and losing decorative and protective properties. For small-size concrete products, sulfur melt impregnation has been proved to be highly efficient, but it is not the same for building units and requires complex impregnation technology at high temperatures (140-150˚C). Besides, materials need to be vacuumized for more effective impregnation. Heating to the indicated temperatures can provoke additional concrete stresses.

In addition to the listed methods for long-term protection of building materials, there are well-tested deep penetration compounds–penetron, xypex, and others [3,4]. These compounds act in the following way: after applied, their active components react with concrete material, building up crystals in the concrete pores, thereby concrete strength and its hydrophobic properties increase. However, wide spread of such materials is limited by their high cost. It should be noted as well that they are fit only for the protection of concrete as building material.

The problem with the creation of a highly-effective method for long-term protection of building materials is in the fact that being exposed to atmospheric factors and microorganisms, water-repellent organic coverings are short-lived by nature. However, almost all nonorganic materials are hydrophilic. Thus, to use them as a basis to provide high water-repellent properties at constant water exposure (swimming pools, banks of the channels, tunnel walls and ceilings, foundations, poling) porous space should be filled deeply enough, and close out water as a result.

Such nonorganic chemical element as sulfur proves to be perspective enough in creating water-repellent coverings, as it is an exception to nonorganic element substances and possesses hydrophobic properties. Sulfur hydrophobic properties have long raised attention of building and road construction specialists. Its application as a binding agent in sulfur concrete products resulted in the acquisition of material of high strength and water-repellent characteristics [7]. In addition, as it was mentioned before, sulfur melt has been applied as impregnation substance for small-size concrete products, but this method did not receive wide acceptance due to implementation difficulties [8]. A new, effective, and convenient way to apply sulfur for long-term protection of porous building materials is offered in this article.

It is appeared obvious that water-repellent agent should penetrate through the material pores deep enough to protect building constructions effectively. Hence, the impregnation compound should be of low viscosity. Thus, in the method offered, treatment of porous surfaces of building materials is carried out in sulfur-containing aqueous compound–composition of calcium polysulfide with spirits and surfactants. The novelty of the approach consists in that at the impregnation stage a water-solvent substance is used–calcium polysulfide, in which sulfur atoms penetrate deeply into the smallest pores of building material. At the drying stage polysulfide molecules break up, and hydrophobic layer of elemental sulfur and calcium hydroxide is formed on pore surface. Calcium hydroxide subsequently transfers into calcium carbonate under carbon dioxide impact. As opposed to varnish and paint materials, sulfur in building

material pores provides them with water-repellent properties for a long period of time.

The effect of the impregnation has been studied with the above suggested compound on physical and mechanical characteristics of vibropressed concrete paving tile of 203×102×60 mm³ in size. The slab was impregnated by immersion into the bath with sulfur-containing solution for 24 hours, impregnation depth amounted to 25 mm. Data obtained in Massalimov [4-6] points to significant reduction in water absorption by 75% and increase of all exploitation characteristics– frost resistance by 2.3 times, strength by 37%, impact resistance by 2.9 times, decrease of abradability by 1.5 times. Efficiency of applying sulfur-containing compound to protect main types of building materials–concrete, brick, aerocrete, and gypsum is outlined in the data below.

Study of the Impregnation Effect on Water Absorption of Building Materials

The following experimental data obtained from the test on various materials in different conditions is presented to demonstrate the opportunities of the method under description for building material protection. The most important factor determining durability of concrete, brick, and other building materials is water absorption by mass W_M, which can be measured by wetting concrete samples, weighed before and after water saturation, in addition, weight gains of the samples in % of dry sample mass have been expressed. Water absorption for a definite sample is calculated according to the formula:

$$W_M = \frac{m_B - m_C}{m_C} \cdot 100$$

, where m_C— mass of the dried sample, g; m_B— mass of water-saturated sample, g.

FIG. 2 and 3 show experimental data on measuring W_M for concrete and brick samples, obtained from immersion into the bath, filled with sulfur-containing solution. W_M values, given in these figures, are average of ten measurements. According to the data in FIG. 2 and 3, impregnation of concrete and ceramic bricks with the solution results in the significant decrease of water absorption ratio, with both impregnation duration and solution density having effect. The increment in consistent impregnation duration results in the decline of W_M monotonous.

FIG. 3 shows results for ceramic brick impregnation with the solutions of different density. The data presented shows that solution density increases as immersing results in W_M decrease. Simultaneously, at brush treatment, differences in W_M value failed to be observed. A repeated recurrence of drying-dipping cycles showed constant W_M value, as well as samples mass after impregnating and drying remained unchanged. This fact indicated that protective hydrophobic layer of the porous space of the impregnated material is not washed out.

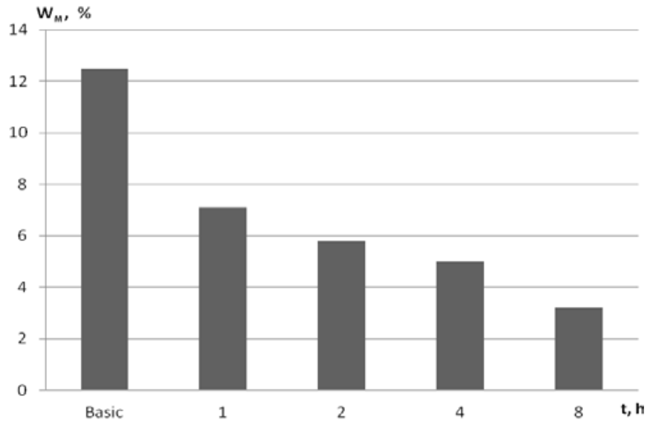

FIG.2 DEPENDENCE OF WATER ABSORPTION BY CONCRETE MASS ON IMPREGNATION DURATION (IMPREGNATION SOLUTION DENSITY R= 1,18 G/CM3)

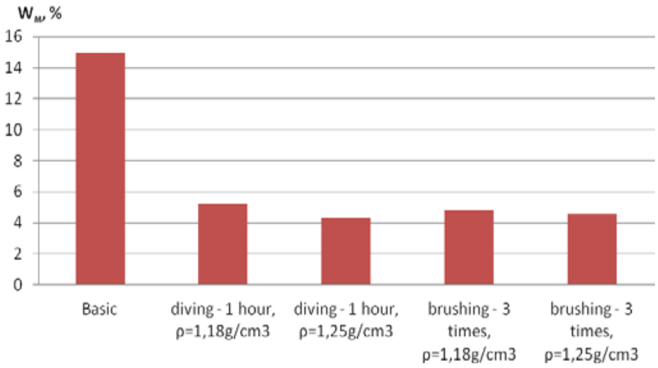

FIG.3 DEPENDENCE OF WATER ABSORPTION BY CERAMIC BRICK MASS ON IMPREGNATION SOLUTION DENSITY AND MATERIAL TREATMENT TYPE

In some cases along with constant, static water impact certain construction parts (foundation and basement blocks, facades) are exposed to frontal water exposure, as, for instance, the rain. To analyze this very important case, a glass tube filled with water was adjusted on the sample surface, contacting place being sealed. The following FIG. 4 presents W_M values for vibropressed concrete tiles, exposed to frontal water impact for 48-hour. Beforehand samples had been impregnated with sulfur-containing solution for different time periods, and then dried. As it is seen from FIG. 4 that 2-hour sample impregnation results in a significant decrease of water intrusion into the material. While 48-hour impregnation with the

solution has made the material virtually waterproof. It is noteworthy that water leaked through the opposite side of unimpregnated samples within 3-4 hours. However, no water was observed on the opposite side of the concrete tile after 2 hours in the impregnation solution and drying.

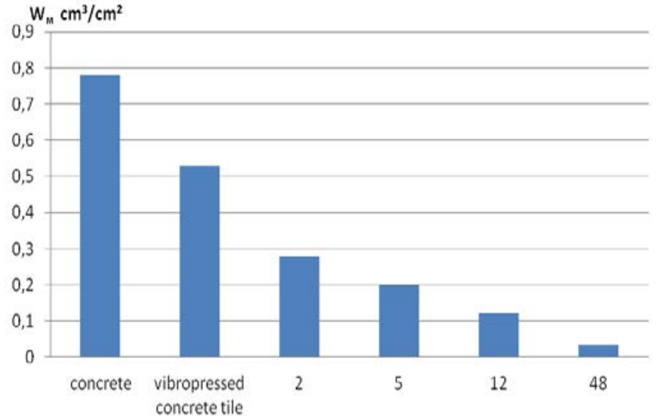

FIG.4 KINETICS OF WATER ABSORPTION FOR VIBROPRESSED TILES DEPENDING ON THE DURATION OF IMPREGNATION WITH SULFUR-CONTAINING SOLUTION BY FULL IMMERSION: 1 - UNIMPREGNATED (TEST) SAMPLE OF HEAVY CONCRETE; 2 - UNIMPREGNATED (TEST) SAMPLE OF VIBROPRESSED CONCRETE TILE; 3 – 2-HOUR IMPREGNATION OF VIBROPRESSED CONCRETE TILE BY FULL IMMERSION; 4 – THE SAME FOR 5 HOURS; 5 – THE SAME FOR 12 HOURS; 6 – THE SAME FOR 48 HOURS.

Practical value of the suggested building material protection is in the fact that after double impregnation either by immersion or by brushing the concrete surface at 1.2-1.5 l/m² solution consumption rate, water stops to filter through heavy concrete and brick surfaces, even at 1-3% residual water absorption, in spite of constant exposure to underground and other waters from the outer wall.

Thus, method of building material impregnation suggested in [1,2,7] can be effectively used to protect all construction units, constantly exposed to water: foundation blocks, pipe culverts and rings, railway sleepers, piles, arches, bridgings, wall sections, curbstones, paving tiles, hydraulic structures, and others. Nonorganic nature of sulfur provides the suggested impregnation compound with the advantage over such extensively used organic materials as polymers. Hence, it is not exposed to destruction in the course of time and provides long exploitation period of the constructions. Technology of processing construction units and products is simple and available: as well as most varnish and paint materials this compound can be applied by brushing, spraying, pouring, immersing at any positive temperatures.

Along with water absorption decreasing for porous building materials, the experiments revealed that compression resistance increases in the treated samples after impregnation with sulfur-containing solution (FIG. 5), as well as the increase of shock resistance (number of strikes before sample destruction) for the impregnated concrete (FIG. 6)

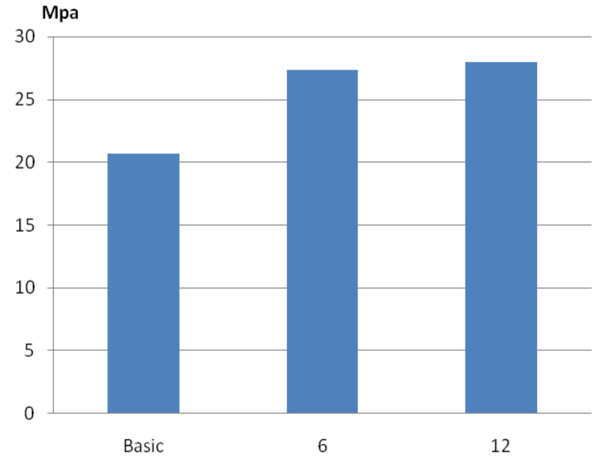

FIG.5 COMPRESSION RESISTANCE OF THE UNPROCESSED AND 12- AND 6-HOUR PROCESSED CONCRETE SAMPLES

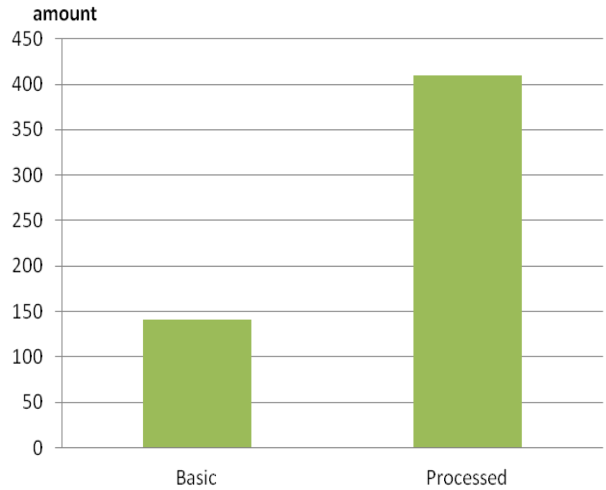

FIG.6 SHOCK RESISTANCE OF THE UNPROCESSED CONCRETE AND IMPREGNATED CONCRETE

It is common knowledge that efficiency of impregnation compounds of deep penetration considerably depends on penetrability. Level of material protection from external (atmospheric and chemical) exposure is rated by impregnation penetrability. Thereby, compound penetration depth has been measured at multiple brushing over the concrete samples. FIG. 7 presents dependence of compound penetration depth on the number of brushing treatments, applied to cement concrete. According to FIG. 7 compound's high penetrability is evident: that is, 6-multiple brushing results in penetration depth of over 10 mm.

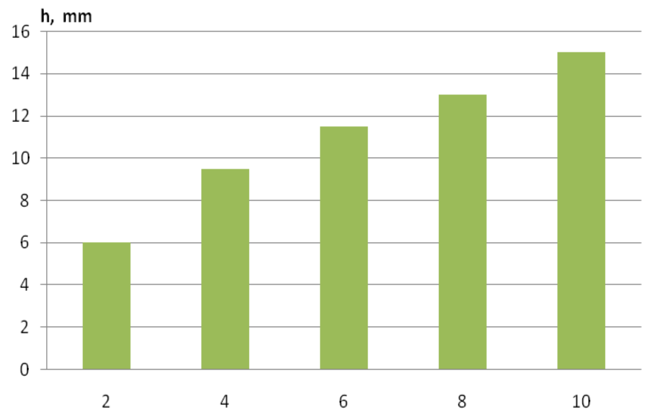

FIG.7 DEPENDENCE OF COMPOUND PENETRATION DEPTH ON THE NUMBER OF SAMPLE BRUSH TREATMENTS

To analyze the nature of the protective coating formed on the material pore surface, the following procedure was carried out. A limestone sample was treated by full immersion into impregnation compound. Limestone is widely used in building industry as facing material. The sample was dried after impregnation, subsequent water absorption analysis revealing 3-fold reduction. Then the sample was dissolved in acid and washed with water through the filter paper on the funnel. Limestone material, composed of $CaCO_3$, was transferred into water-soluble $CaCl_2$ as a result of hydrochloric acid treatment and subsequently washed out with water. Yellow powder was left on the filter after washing out. Measurements of particle size distribution (see FIG. 9) using laser analyzer showed that average particle size is 25 nm, and maximum particle size is under 50 nm. X-ray pattern shot using Rigaku IV revealed orthorhombic structure (see FIG. 10).

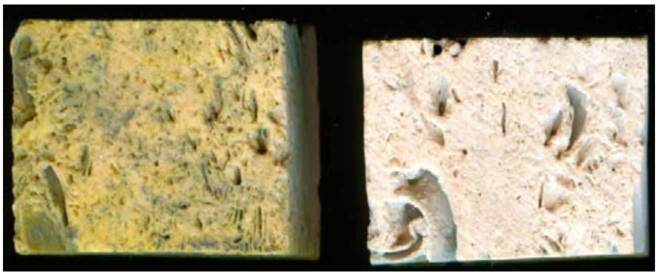

FIG. 8 LIMESTONE SAMPLES: PROCESSED (LEFT), INITIAL (RIGHT)

Along with the analysis of the sulfur powder obtained by extracting it from limestone, processed and unprocessed concrete splits were analyzed using CMM-2000T scan multimicroscope. After the samples were treated with impregnation compound nanoparticle formations were observed on the surface of the concrete pores (with diagonal sulfur particle size ranging from 20 to 150 nm, and height from 2 to 10 nm, see FIG. 11), which was identified with sulfur particles.

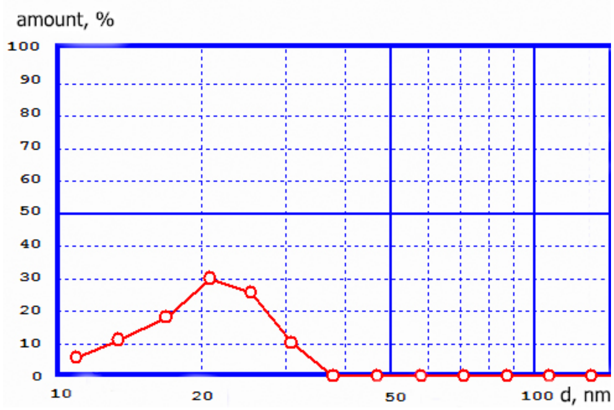

FIG. 9. SIZE DISTRIBUTION OF SULFUR PARTICLES, EXTRACTED FROM LIMESTONE POROUS STRUCTURE

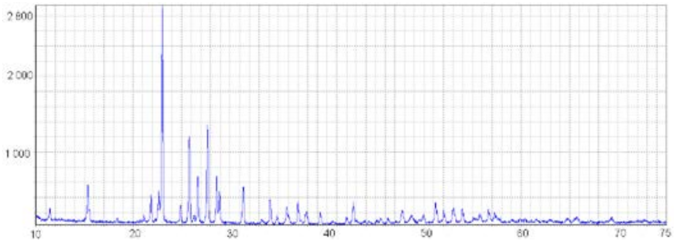

FIG.10 X-RAY PATTERN OF ELEMENT SULFUR PARTICLES, EXTRACTED FROM LIMESTONE POROUS STRUCTURE

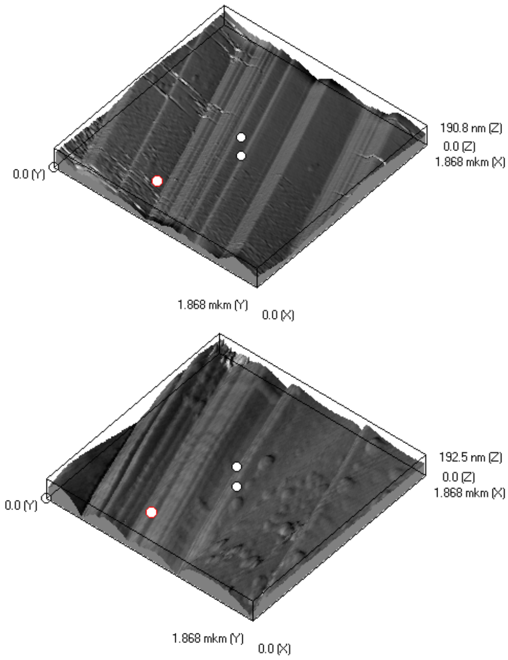

FIG. 11 CONCRETE SPLIT APPEARANCE: TOP – UNPROCESSED; BOTTOM – PROCESSED

Conclusions

1. Impregnation solution treatment results in water absorption reduction and improvement of mechanical characteristics due to nanosize particle coating formed

in the pores of building materials. The coating is highly adhesive to the material and chemically resistant to water exposure and chemical agents.

2. The suggested method is practically feasible, as the treatment described can be implemented by brushing, immersing, spraying at indoor temperature, similar to other varnish and paint materials. Protection level can be regulated, varying time and repetition of the process. The impregnation solution possesses rather high penetrability, penetrating into the smallest pores, which together with nonorganic surface nature makes it effective and universal means for long-term protection.

3. The important practical significance of the suggested building material protection is in the fact that after double impregnation either by immersion or by brushing the concrete surface at 1.2-1.5 kg/m^2 solution consumption rate, water stops to filter through heavy concrete and brick surfaces, even at 1-3% residual water absorption, in spite of constant exposure to underground and other waters from the outer wall.

4. Sulfur-based impregnation solution is multipurpose, considerably reduces water absorption not only for concrete, but for other building materials as well– ceramic and lime-sand brick, autoclave aerocrete, gypsum, asbestos-cement materials. Thus, they are perspective to protect outer surfaces of enclosures, concrete pavement products, wall and roofing items and can be used to maintain operational reliability of old building outer walls made of lime-sand and ceramic bricks, ceramsite concrete wall panels.

5. The suggested method can be used to protect building materials under static water impact. This includes culverts, flumes, tunnels, bridges, curbs, kennels in road services; foundations, cellars, basements, roofs in industrial and civil engineering; wells, heating mains, and others in housing and communal services.

6. Based on the above-stated, it can be noted that the utilization of sulfur-containing impregnation compound allows increasing longevity of building materials and products, operating life of the existing buildings and constructions, as well as those under erection; reducing expenses on building exploitation and repairs; creating comfortable conditions for premises exploitation; preserving original appearance of the outer building and construction surfaces and reducing dirt accumulation; as well as preventing premises from mould and fungi. Thus, the invented method is versatile and effective for protection of concrete, ceramic, lime-sand and other building materials and products, exposed to atmospheric impact, such as long-term moisture exposure, alternating temperatures, solar radiation, biochemical destruction.

ACKNOWLEDGEMENT

Authors would like to thank the Ministry of Education and Science of Russian Federation for the financial assistance in the form of grant under the framework of the Federal Target Programme "Scientific, research and pedagogical personnel of innovative Russia for 2009-2013".

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